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Education and Research on Reactor Physics at NTHU in Taiwan

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1. Introduction

The history of nuclear engineering programs at National Tsing Hua University (NTHU) can be traced back to 1956 when the university was re-established in Taiwan. The undergraduate program of the Department of Nuclear Engineering was established in 1964, while the master program and doctor program were established in 1970 and 1981, respectively. After Three Mile Island accident and Chernobyl disaster, the nuclear industry worldwide had suffered in great depression. The situation also affected the enrollment of the nuclear engineering programs at NTHU in Taiwan. In 1997, the department decided to change its name to the Department of Engineering and System Science (ESS) by expanding its research capabilities into more diversified fields, such as nano-technologies, microelectromechanical systems, and low carbon green energy resources. Still, nuclear engineering remains as one of the important programs in ESS to inspire and train the young generation to become professional nuclear engineers and scientists.

In 21th century, the issues of global warming and climate changes become more and more severe. Facing the issues of energy shortage and the pressure of reducing the emission of greenhouse gases, nuclear power, a stable and non-carbon-emission energy source, has regained wide attention and interest. The renaissance of nuclear engineering helped us to reestablish the Institute of Nuclear Engineering and Science (NES) at NTHU in 2007. Currently, there are 26 professors including adjunct faculties in NES. The faculty members have various professional specialties in nuclear engineering and science, and can provide complete and high-quality education in nuclear engineering. NES have cooperated with several national research institutes in Taiwan and worldwide as well.

Among the six types of the Gen-IV reactors, the VHTR (Very High Temperature Reactor) is a good candidate for the next generation power reactor, high-temperature applications and the production of hydrogen. Therefore, it is a suitable type of reactor for us to study and to join the international collaboration research program. For example, USDOE supports research projects on VHTR in INL for years. The HTTR operated by JAEA first reaches its full power of 30 MW in 1999. The core can reach high temperature for hydrogen production. Both INL and JAEA are more than happy to collaborate with the Taiwanese team in the research area of VHTR. The authority agencies in Taiwan also support a long-term and on-going research project in this area starting from 2010. It includes three major sub-projects in reactor physics, thermal hydraulics, and material researches. In this paper, we give a brief introduction regarding the education and research activities relating to reactor physics at NTHU in recent five years.

2. Nuclear Engineering Curriculum in ESS and NES

In the first semester of sophomore year, students can take “Introduction to Nuclear Engineering” for an overview of nuclear engineering. In the following second semester, for those who interested in nuclear engineering and would like to learn more in this field are suggested to take “Principles of Nuclear Engineering I.” In this course, fundamental nuclear physics, radiation interaction with matter, and diffusion theory are introduced, covering chapters 1-7 in Lamarsh textbook [1]. For junior and senior students in this curriculum, the following courses “Principles of Nuclear Engineering II – Radiation Safety”, “Principles of Nuclear Engineering III – Nuclear Power Reactor Safety”, “Nuclear Power System”, “Principles in Radiation Measurements”, and “Radiation Detection and Measurement Laboratory” are suggested.

On the other hand, “Principle of Nuclear Engineering I” is also offered by the institute of NES in fall semester for graduate students who didn’t take this course during the undergraduate study. In NES, the main research areas includes “reactor physics and shielding”, “nuclear thermal hydraulics”, “nuclear materials”, “nuclear science” and” beam technology”. A variety of advanced courses are offered in NES to help students learning and to pursue careers in these research areas. For example, NES offers “Reactor Physics I”, “Reactor Physics II”, “Nuclear Reactor Dynamics”, “Monte Carlo Method”, “Radiation Shielding” and “Radiation Transport Calculations and Applications” for those students majored in reactor physics and shielding. These courses provide students with the fundamental knowledge and professional skills to facilitate their thesis studies in this field.

3. Reactor Physics Studies in VHTR project

This section summarizes the reactor physics studies supported by the VHTR project in past years. In average, we have approximately two graduate students per year participating in the project and majoring reactor physics related topics. Most studies can be categorized into the following five themes:

- Cross-section generation
- Monte Carlo full-core calculations
- Lattice/Assembly calculations
- Hexagonal nodal diffusion code development
- Neutronic and thermal-hydraulic coupling

Some studies have been completed and some are still on-going. All these studies in the end will constitute a complete flowchart (Fig. 1) and platform for our future VTHR core analysis and design.

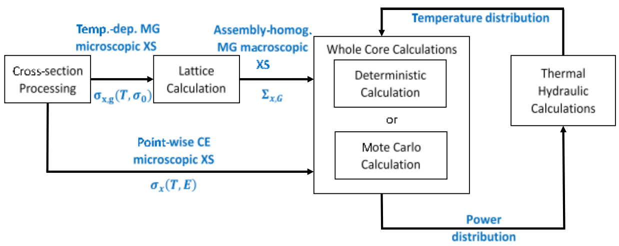

Fig. 1. Flowchart of a typical reactor core analysis

3.1 Cross-Section generation

Both deterministic and Monte Carlo methods in neutronic analyses rely on accurate temperature-dependent cross sections. T.W. Lin in his thesis study investigated the effects of various treatments of temperature-dependent cross sections on a hot HTTR criticality calculation, which involves many nuclides in the core configuration and a detailed temperature distribution. By using MCNP5, the author considered and compared five popular cross-section treatments: (1) approximate temperatures by rounding up or down to the nearest available temperature in data libraries, (2) a pseudo material method based on interpolation through mixing of nuclides at two temperatures, (3) the makxsf utility with Doppler broadening and interpolation to create customized libraries, (4) an on-the-fly methodology to create the Doppler broadened data sets, and (5) the fundamental NJOY nuclear data processing system to generate data libraries at problem-specific temperatures, including nuclear reaction and S(α,β) data. [2,3]

3.2 Monte Carlo full-core calculations

Monte Carlo simulations are popular in radiation transport applications because of accurate representations in problem geometry and particle phase space. In VTHR related studies, M.H. Chiang, J.Y. Wang, and Y.C. Tien performed full-core criticality and burnup calculations for high-fidelity VHTR models by using SCALE6 or MCNP5/X. Although time-consuming, the continuous-energy Monte Carlo results are generally considered to be most accurate and reliable, and therefore suitable for serving as a benchmark for future comparisons.

The VTHR fuel element presents an intrinsic doubly heterogeneous geometry. J.Y. Wang performed a series of full-core HTTR criticality calculations with SCALE6 using various unit-cell options in order to systematically investigate their effects on multigroup neutronic analysis. The comparison confirmed that the DOUBLEHET treatment can lead to a more satisfactory agreement with the continuous-energy result [4]. M.H. Chiang and J.Y. Wang successfully established two detailed full-core models of HTTR to study its neutronic properties. Compared with experimental data, the two models show a consistent bias of approximately 20-30 mk overestimation in effective multiplication factor for a wide range of core states. Most of the bias could be related to the ENDF/B-VII.0 cross-section library or incomplete modeling of impurities in graphite. In addition, the study shows that multigroup calculations tend to underestimate the system eigenvalue by a constant amount of ~5 mk compared to their continuous-energy counterparts [5,6]. To explore the effect of temperature distribution on neutronic calculations, Y.C. Tien compared two HTTR calculations, one with a realistic temperature distribution and the other with a uniform temperature distribution. The result showed non-negligible differences up to 14% in power distribution [7]. He also extended his study from HTTR to GTHTR300, a newly proposed VHTR design in JAEA based on improved HTTR fuel element.

3.3 Deterministic reactor core analysis

Monte Carlo transport calculations are excellent for benchmark calculations, but generally not practical for core analyses and design. Typical neutronic calculation for LWRs can be divided into two major parts, i.e., the lattice physics calculations based on transport theory and the whole core calculations based on diffusion theory. Deterministic methods are mainly used in these calculations because of superior computation efficiencies. Similar approaches and methodologies were adopted in our VHTR studies.

3.3.1 Lattice/Assembly calculations

From September 2012 to November 2012, M.H. Chiang had the opportunity to go to INL to learn the DRAGON code for VHTR assembly calculations. He also used T-NEWT, a 2D deterministic transport code in SCALE6 package, to perform similar analyses for comparison [8]. In addition, the study confirmed that the assembly calculation in VHTR will be significantly affected by the configuration of surrounding blocks because of a much longer neutron mean free path in VHTR than that in traditional LWR [9]. Therefore, a super-cell calculation that includes the neighboring fuel or reflector blocks is necessary in the assembly level calculation. The study also indicated that the traditional 2-group cross-section representation is not accurate enough to reproduce the neutronic properties of the fuel block of concern and will cause non-negligible errors in the next-step whole core calculation. The number of groups in cross sections used to represent the homogenized fuel block is suggested not less than nine in order to generate appropriate cross sections.

3.3.2 *Hexagonal nodal diffusion code development*

The aim of our VHTR project in reactor physics includes a development of an in-house nodal diffusion code that can handle hexagonal geometry. During 2010-2012, two master students, C.W. Chang and J.Y. Wang, went to INL to learn the hybrid nodal Greens function method in neutronic calculations for both rectangular [10] and hexagonal geometries [11]. Recently, a Ph.D. student T.Y. Lin has successfully demonstrated this capability by applying conformal mapping technique to his developing nodal diffusion code. The details of his study can be found in another paper presented in this conference [12].

3.4 Neutronic and thermal-hydraulic coupling

The temperature change in reactor core affects the power distribution, which in turn results in a new temperature distribution. Therefore, neutronic calculations must be coupled with thermal hydraulic calculation to obtain converged results of both temperature and power distributions. Recently, we conducted a preliminary study by introducing a simple 1D thermal hydraulic model into the Monte Carlo core calculations. Starting from an initial guess for the temperature distribution in the core, we can obtain a power distribution through neutronic calculations. Based on this power distribution, the thermal hydraulic calculation will give us an updated temperature distribution. The process will be repeated until power and temperature distribution both converged. More details about this coupling scheme will also be presented in this conference [13].

4. Summary and Future Work

ESS and NES at NTHU provide a variety of courses related to nuclear engineering and science that attract many young students that are interested in this field. In addition to training young generation, both faculties and students in ESS and NES also actively and continuously take part in campaigns providing correct nuclear energy related information to various societies in Taiwan.

Thanks to the government's long-term support in the VHTR research project, we have gradually established our capabilities in various key ingredients in reactor physics that will eventually lead to a complete platform for VHTR core analysis and design.

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